Hadron Structure and Spectroscopy

Precision probes of quark/gluon structure of hadrons

A wealth of experimental facilities probe hadron structure with unprecedented precision:

- **Interaction precisely known from Standard Model**
- **Weak coupling of electroweak interaction and asymptotic freedom at high energies for strong interactions remove ambiguities of reaction mechanism.**

Lepton scattering: e^-, μ^-, ν $\quad$ **10^0 - 10^2 GeV**

Bates, CEBAF, SLAC, Hermes, CERN...

High energy hadron scattering:

eg. Drell Yan: $pp \to l^+ l^-$

Fermilab, RHIC spin...

Observables

- **Form factors**

  Elastic scattering: $\langle N | J^\mu(q) | N \rangle \to G_E, G_M$

  Low q characterizes spatial distribution of charge and current

  Parity-violating e^- **scattering**

  Form factor for weak neutral current

  Separate strange quark contribution

  G_M^S **and** $r_S^2 = -6\frac{dG_E^S}{dQ^2}$ **measured at Bates, CEBAF**

- **Structure functions**

  Deep inelastic scattering: $\int d^4x e^{iq.x} \langle ps|J^\mu(x)J^\nu(0)|ps\rangle$

  $\rightarrow$ **structure fns.** $F_1(\nu,Q^2), F_2(\nu,Q^2), g_1(\nu,Q^2), g_2(\nu,Q^2)$

  Characterize distribution of quarks and gluons as a function of momentum fraction x

  $F's \sim$ **spin averaged parton dist.** $\frac{1}{2}[q_\uparrow(x) + q_\downarrow(x)]$

  $g's \sim$ **spin dependent parton dist.** $\frac{1}{2}[q_\uparrow(x) - q_\downarrow(x)]$

  Moments of structure functions are related to operators calculable with lattice QCD:

  $$\langle ps|\bar{\psi}_f \gamma_{\{\mu_1} D_{\mu_2} \cdots D_{\mu_n\}} \psi_f|ps\rangle \sim \int dx x^{n-1} \tfrac{1}{2}[q_\uparrow(x) + q_\downarrow(x)]$$

  $$\langle ps|\bar{\psi}_f \gamma_5 \gamma_{\{\sigma} D_{\mu_1} \cdots D_{\mu_n\}} \psi_f|ps\rangle \sim \int dx x^{n} \tfrac{1}{2}[q_\uparrow(x) - q_\downarrow(x)]$$

  $$\langle ps|F_{\alpha\{\mu_1} D_{\mu_2} \cdots D_{\mu_{n-1}} f^\alpha_{\mu_n\}}|ps\rangle \sim \int dx x^{n-1} g(x)$$

Need Terascale computation for first principles calculation of hadron structure

Particularly sensitive to chiral limit

Pion cloud dominates magnetic moment

Sea quarks crucial

Direct coupling of probe to sea quarks

High statistics essential

Gluon operators - vacuum fluctuations

D_μ **in moment expansion**

Calculating coupling of probe to sea quarks

Large errors in current quenched calculations

Form Factors: $\langle r^2 \rangle$ **20 - 50% too small**

Structure fns: $\langle x \rangle$ **50 - 75 % too high**

Physics opportunities

- **Form factors**

  Special emphasis of strange form factors

- **Moments of structure functions**
- **Moments of light cone wave functions**
- $\Sigma_{\pi N} \sim \langle P|m\bar{q}q|P\rangle$
- **Transition form factors to excited states**
- **Spectroscopy**

  Glueballs and their mixing

  Gluonic excitations in hadrons

  Exotic states : H, ...

- **Physics of confinement and chiral symmetry breaking**

  Role of instantons, zero modes, monopoles, and center symmetry

Algorithmic developments crucial

Chiral fermions

Improved action

Nonperturbative renormalization

Improved methods to measure gluons, derivatives, and disconnected diagrams

Physics program

Initial phase

- Collaboration with Wuppertal / Jülich group to calculate strange form factors and moments of structure functions using their full QCD SESAM configurations

Second phase

- Share in coherent effort to produce large ensemble of full QCD configurations on Terascale SSI facility for multiple applications
- Calculate hadron structure observables

Role of international collaboration

- Collaborate in development of algorithms and software
- Generate complementary configurations for use in joint projects
- Support exchanges of senior and junior staff
- Joint meetings and workshops